ADMIN. 1000A (REV. 8/76)

STATE OF MINNESOTA

Office Memorandum

DEPARTMENT Health

TO : Jim Pankanin <5E·WHME>
U.S. Environmental Protection Agency
Water & Hazardous Materials Research
230 S. Dearborn Street
Chicago, Illinois 60604

DATE: 9/25/81

FROM : Mike Convery

PHONE: 612-296-5297

SUBJECT: Hickok Report 6-18-12 - G.C. Well System / Task 1/2 Contract language

I am forwarding to you for your review copies of the latest Hickok report and the proposed contract language for Tasks 1 + 2 of the E.P.A. Reallocation grant for $200,000. Please return comments to me by Monday - Oct. 5, 1981

545 Indian Mound
Wayzata, Minnesota 55391
(612) 473-4224

September 22, 1981

Mr. Michael Convery
Minnesota Department of Health
717 SE Delaware Street
Minneapolis, Minnesota 55440

Re: St. Louis Park Groundwater Contamination Study

Dear Mike:

Enclosed is memorandum Number G18-12 entitled, "Gradient Control Well System" for the referenced project.

As you requested in your telephone conversation with John Erdmann on September 18, we are documenting how we plan to handle the remaining work products, as follows. First, the draft of the final report will be submitted on September 30. Second, a memoradnum documenting refinement of the USGS model will not be produced. Instead, the memorandum on information deficiencies will be broadened beyond the scope of the USGS model (Prairie du Chien-Jordan aquifer only) to include all aspects of the contamination. Finally, conclusions and recommendations of the study will not be produced in a separate memoradnum, but instead will appear first in the draft of the final report.

Respectfully submitted,

EUGENE A. HICKOK AND ASSOCIATES

Eugene A. Hickok

Eugene A. Hickok, P.E. by JBE
President

bt

Enclosure

cc: Richard Ferguson, MPCA
Marc Hult, USGS

NON-RESPONSIVE [redacted]

PANKANIN

G18-12

SEPTEMBER 22, 1981

ST. LOUIS PARK GROUNDWATER CONTAMINATION STUDY
GRADIENT CONTROL WELL SYSTEM

A GRADIENT CONTROL WELL SYSTEM IS PROPOSED FOR THE REMEDY OF GROUNDWATER CONTAMINATION BY POLYNUCLEAR AROMATIC HYDROCARBONS (PAH) IN ST. LOUIS PARK, MINNESOTA. THE CONCEPTUAL BASIS AND DESIGN OF THE REMEDIAL PLAN FOR EACH AFFECTED AQUIFER ARE PRESENTED. ALSO INCLUDED IN THIS MEMORANDUM ARE DISCUSSIONS OF HYDROGEOLOGY, GROUNDWATER QUALITY ASPECTS, MONITORING AND SUPPLEMENTAL CONTROL, AND SECONDARY IMPACTS AS RELATED TO IMPLEMENTATION OF THE PROPOSED GRADIENT CONTROL WELL SYSTEM. THIS MEMORANDUM REPRESENTS COMPLETION OF TASK 2120 OF THE REFERENCED PROJECT.

include monitoring system

reviewed 10/14/81
J.P

ST. LOUIS PARK GROUNDWATER CONTAMINATION STUDY
GRADIENT CONTROL WELL SYSTEM

I. INTRODUCTION

The principal aquifers of the St. Louis Park area considered here are the Middle Drift, Platteville, St. Peter, Prairie du Chien-Jordan, Ironton-Galesville and Mt. Simon-Hinckley. Analyses of groundwater samples from wells in the St. Louis Park area indicate polynuclear aromatic hydrocarbons (PAH) are present in all of these aquifers. The source of the PAH compounds is believed to be the former Republic Creosote site in St. Louis Park (Figure 1). PAH migration has been attributed to leakage from the disposal pond south of the site and the effects of multi-aquifer wells (Sunde, 1974; Hult and Schoenberg, 1981).

The gradient control well system presented in this memorandum is designed to control the movement of, and eventually remove, groundwater contaminated with PAH compounds. For the purpose of remedial plan design, groundwater contamination is defined as the presence of 1) any individual carcinogenic PAH concentration greater than 2.8 nanograms/liter or 2) any other individual PAH concentration greater than 28 nanograms/liter. Also included in this memorandum are discussions of hydrogeology, groundwater quality aspects, monitoring and supplemental controls and secondary impacts as related to implementation of the gradient control well system.

II. HYDROGEOLOGY

A. General Description

The stratigraphic sequence of the aquifers and separating aquitards in the St. Louis Park area is shown in Figure 2, and the corresponding hydrologic parameters are summarized in Table 1. The uppermost aquifer in the sequence is the Middle Drift, a glacial sand and gravel aquifer which varies in thickness from about 20 to 40 feet. The Middle Drift is overlain by a low hydraulic conductivity glacial till layer of varying thickness. Another low conductivity layer, the basal (or lower) drift, separates the Middle Drift and underlying Platteville aquifer. At the base of the Platteville lies the Glenwood confining bed. This hydrologic unit consists of the Glenwood shale and a shaly transition zone in the upper St. Peter. The Glenwood confining bed greatly inhibits downward flow from the Platteville to the St. Peter. Above this bed, water from the disposal pond has flowed downward into the Middle Drift and Platteville aquifers through which it is conveyed in a generally eastward direction.

The St. Peter sandstone aquifer lies below the Glenwood confining bed. The basal St. Peter is consistently silty and thus behaves as an aquitard separating the St. Peter and Prairie du Chien aquifers. Underlying the Prairie du Chien dolomite is the Jordan sandstone aquifer. Since no confining bed separates these two aquifers, they are considered as a single unit, the Prairie du Chien-Jordan. Both the St. Peter and the Prairie du Chien-Jordan aquifers receive recharge from the Lake Minnetonka area and

Table 1

HYDROLOGIC PARAMETERS*

Hydrologic Unit	Approximate Upper Contact Elevation (ft above NGVD)	Approximate Thickness (ft)	Transmissivity (gpd/ft)	Horizontal Hydraulic Conductivity (gpd/ft^2)	Vertical Hydraulic Conductivity (gpd/ft^2	Effective Porosity
Upper Drift	Variable	5–40	—	—	—	—
Till	Variable	2–10	—	—	—	—
Middle Drift	Variable	20–40	7,600–31,300[6]	250–1,040		0.30[4]
Basal Drift	Variable	10–30	—	—	0.03[4]	—
Platteville	811–840	0–30	0–37,000[2]	—	—	0.05[2]
Glenwood Confining Bed	805–811	0–6	—	—	1.2×10^{-4}[2]	0.25[2]
St. Peter	805	110	20,000[7,8]	180	—	0.30[1]
Basal St. Peter Confining Bed	695	55	—	—	0.02[2]	0.20[4]
Prairie du Chien-Jordan	640	210	50,000–150,000[1]	240–710	—	0.15[1,3]
St. Lawrence-Franconia	430	190	—	—	0.01[5]	0.10–0.30[2]
Ironton-Galesville	240	50	1,050	21[5]	—	0.25[1]
Eau Claire	190	90	—	—	0.007[5]	0.10–0.30[2]
Mt. Simon-Hinckley	100	265	12,000[1]	45	—	0.22[1]

*Subscript denotes reference as follows (see bibliography):

1. Norvitch et al., 1973
2. Hult, personal communication, July 24, 1981
3. Reeder et al., 1976
4. Barr, 1977
5. Aquifer Thermal Energy Storage Project, USGS
6. Derived from data in Hult and Schoenberg, 1981
7. Norvitch and Walton, 1979, as cited by Hult, personal communication, July 1981
8. Mogg, 1961, as cited by Hult, personal communication, July 1981.

discharge to the Mississippi River. Therefore a natural eastward flow through these aquifers occurs in the St. Louis Park area. This flow pattern is locally perturbed by the effects of pumping wells.

Below the Jordan sandstone lies the St. Lawrence dolomite-siltstone and Franconia sandstone. These two units comprise a thick, low conductivity aquitard separating the Jordan and Ironton-Galesville sandstone aquifers. The siltstone and shale sequences of the Eau Claire act as an aquitard separating the Ironton-Galesville from the Mt. Simon-Hinckley sandstone aquifer. Unlike the St. Peter and Prairie du Chien-Jordan, the Ironton-Galesville and Mt. Simon-Hinckley aquifers are not hydraulically connected to Lake Minnetonka or the Mississippi River. Therefore, no significant natural flow trend is presumed to exist in these aquifers as is indicated by contours of the Mt. Simon-Hinckley piezometric surface during the winter of 1970-71 (Norvitch et al., 1973).

B. Bedrock Valley

A buried bedrock valley cutting through the Platteville and Glenwood into the St. Peter is believed to exist southeast of the site as shown in Figure 1 (Hult and Schoenberg, 1981). This is evidenced by the absence of the Glenwood shale in logs of wells W111* and W122. The significance of the bedrock valley is attributed to the possible conveyance of contaminated water from the disposal pond to the valley through the Middle Drift and Platteville aquifers. In the buried valley the exposed

*Well identification follows USGS notation as in Hult and Schoenberg (1981).

St. Peter is expected to receive inflow from these aquifers due to natural hydraulic potential differences.

July 22-24 and March 3-4, 1981 water level data from Platteville monitoring wells display preferential groundwater flow directions to the east and southeast around the buried valley. This could be due to low hydraulic conductivity basal drift overlying the Platteville which diminishes toward the valley. Groundwater approaching the valley would tend to flow in the directions of continuous Platteville rather than into the low conductivity basal drift. Corresponding water level data from Middle Drift observation wells indicate flow in this aquifer is generally east across the valley. Downward leakage from the Middle Drift, through the basal drift and into the St. Peter could occur in the bedrock valley.

III. REMEDIAL PLANS

A. Conceptual Base

Groundwater flows in response to a hydraulic gradient. Natural gradients occur in aquifers possessing natural recharge and discharge areas. Pumping induced gradients exist due to aquifer discharge into wells. At any point within an aquifer, the gradient exerted by a pumping well is given by

$$I = \frac{Q}{2\pi rT} \tag{1}$$

where I = gradient toward the well;

Q = well discharge rate;

T = aquifer transmissivity; and,

r = radial distance from well.

Gradients produced by multiple pumping wells may be vectorially added to determine the resulting gradient at any point within the aquifer. This approach was applied in the remedial plan designs for the Mt. Simon-Hinckley and Ironton-Galesville aquifers in which groundwater movement is assumed to be dominated by pumping induced gradients.

The Middle Drift, Platteville, St. Peter and Prairie du Chien-Jordan aquifers possess generally eastward natural gradients which must be incorporated in the design of gradient control (or "recovery" or "interception") well systems. Locations and pumping rates of proposed recovery wells in these aquifers were based on the hydraulics of a well pumping in a uniform flow field as presented by Todd (1964). For a well pumping at a rate Q in an aquifer with transmissivity T and uniform gradient i, the definition of the resulting capture streamline or area of influence of the well is

$$x = -y \cot \left(\frac{2\pi Ti}{Q} y\right) \tag{2}$$

where x and y are cartesian coordinates as depicted in Figure 3. Equation (2) defines the aquifer area in which all groundwater will flow toward and eventually be withdrawn by the recovery well. As the distance upgradient from the well increases, the capture area width approaches

$$W = \frac{Q}{Ti} . \tag{3}$$

Groundwater within a distance x_o downgradient from the well will be captured by the well where

$$x_o = \frac{-Q}{2\pi Ti} . \tag{4}$$

Equations (2) through (4) can be used to approximate recovery well pumping rates required to capture upgradient zones of groundwater contamination if the aquifer transmissivity (T) and background gradient (i) are known. This approach was used in the design of remedial plans for the Middle Drift, Platteville, St. Peter and Prairie du Chien-Jordan aquifers.

B. Mt. Simon-Hinckley Aquifer

Groundwater contamination of the Mt. Simon-Hinckley is assumed to be localized in the vicinities of the on-site Hinckley (W23) and Milwaukee Railroad (W38) multi-aquifer wells (Figure 4). Contours of the Mt. Simon-Hinckley piezometric surface during the winter of 1970-71 indicate groundwater movement in the aquifer is dominated by pumping induced gradients (Norvitch et al., 1973). St. Louis Park (SLP) municipal wells 11, 12 and 13 are Mt. Simon-Hinckley wells in close enough proximity to exert pumping induced gradients in the contaminated zones and thus influence the movement of this water. In the past decade, groundwater flow within the area has been convergent toward SLP 11 since it has maintained the highest discharge rate of the three municipal wells. Based on 1979 and 1980 total pumpage records, the present average pumping rates for these wells are approximately 600 gallons per minute (gpm) for SLP 11 and 300 gpm for SLP 12 and 13 each. Three remedial plans for the Mt. Simon-Hinckley were considered, all of which necessitate continued heaviest pumpage by SLP 11 or by newly constructed recovery wells nearer the assumed sources of contamination.

The first plan is to continue the present 1979-1980 pumping pattern in the aquifer with an average discharge of 600 gpm or greater from SLP 11 and average discharges from SLP 12 and 13 at rates up to one-half that of SLP 11. In so doing, contaminated groundwater originating at the two multi-aquifer wells will continue to move toward and eventually be withdrawn by SLP 11. This well would then require treatment in order to continue providing municipal water supply.

The second plan is the rapid recovery of contamination by two proposed recovery wells, R-W23 and R-W38 (Figure 4), constructed adjacent to the Hinckley (W23) and Milwaukee Railroad (W38) wells, respectively. To insure convergent flow of contaminated groundwater toward the recovery wells, they should be pumped equally at an average rate of 300 gpm or greater each, use of SLP 11 should be discontinued and the average discharges of SLP 12 and 13 should not exceed half the combined discharge of the recovery wells.

The third remedial plan is to withdraw all contaminated groundwater through one recovery well, RW2 (Figure 4), located midway between the Hinckley (W23) and Milwaukee Railroad (W38) wells. Again, to insure that flow of contaminated groundwater converges toward the recovery well, it should be pumped at an average rate of 600 gpm or greater, SLP 11 should be shut down and wells SLP 12 and 13 should be used at rates less than or equal to half that of the recovery well.

C. Ironton-Galesville Aquifer

As in the Mt. Simon-Hinckley aquifer, contamination of the Ironton-Galesville is assumed to be localized in the vicinities of the multi-aquifer Hinckley (W23) and Milwaukee Railroad (W38) wells (Figure 4). Groundwater flow within the aquifer is assumed to be dominated by pumping induced gradients. Since little or no use of this aquifer occurs within the area, the migration of contaminated groundwater from the source multi-aquifer wells should be minor. Analagous to the latter two Mt. Simon-Hinckley remedial plans, Ironton-Galesville groundwater contamination could be retrieved by two recovery wells located adjacent to the multi-aquifer source wells or by one centrally located recovery well. A total pumping rate of 125 gpm is recommended for either of these plans.

D. Prairie du Chien-Jordan Aquifer

Eastward trending groundwater flow through the Prairie du Chien-Jordan aquifer occurs in the St. Louis Park area. Potentiometric contours for the winter of 1970-71 (Norvitch et al., 1973) and January and June 1981 (Hult and Schoenberg, 1981) indicate an eastward gradient of about 10 feet per mile. Two remedial plans were considered in which the eastward flow of contaminated groundwater would be intercepted and withdrawn by wells. The first plan is to maintain average discharges of 800 gpm from St. Louis Park municipal well 4 (SLP 4, Figure 5), 1000 gpm from the Park Theater well (W70) and 1500 gpm from Old SLP 1 (W112). The second plan is to pump SLP 4 and the Park Theater wells at average rates of 800 gpm and 1000 gpm, respectively, and construct a new well, RW1, just east of Bass Lake to be pumped at an average rate of 800 gpm. The resulting areas of capture for these plans are shown in Figure 5, assuming a transmissivity of 100,000 gpd/ft.

The proposed new well RW1 effectively replaces the interception performance of Old SLP 1 (W112) in the first plan, but use of Old SLP 1 would also be beneficial in the second plan since it would withdraw groundwater of suspected highest contamination. In conjunction with either of these plans it is suggested that (1) municipal demands be partially met by treating a combined average discharge of 800 gpm or greater from SLP 10 and 15, and (2) heavy use municipal wells located on or near the northern, southern and western extent of presently known contamination (i.e. SLP 5, 6, 7, 9, 14, 16 and Hopkins 3) be discouraged. This additional action will tend to contract the contaminant plume and allow a somewhat shorter cleanup duration.

E. St. Peter Aquifer

As in the Prairie du Chien-Jordan aquifer, groundwater flow through the St. Peter is generally west to east in the St. Louis Park area. Water levels in St. Peter wells during March 3-4 and

July 22-24, 1981 indicate a maximum eastward gradient of about 10 feet per mile. Assuming a transmissivity of 20,000 gpd/ft., the eastward flow of contaminated groundwater could be collected by one proposed well, RW3 (Figure 6), pumping at an average rate of 300 gpm. This well would also capture groundwater which may enter the St. Peter from the overlying Platteville or Middle Drift aquifers through the bedrock valley.

F. Platteville Aquifer

March 3-4 and July 22-24, 1981 water level data from Platteville monitoring wells indicate local groundwater flow diverges to the southeast and east around the buried bedrock valley. Two recovery wells, RW4 and RW5 (Figure 7), are proposed to intercept the southeastward and eastward trending flow of contaminated groundwater. The maximum southeastward and eastward gradients displayed by the water level data are about 20 and 10 feet per mile. Using these gradients and a transmissivity of 18,000 gpd/ft, the capture area shown in Figure 7 would be produced by pumping wells RW4 and RW5 at average rates of 150 gpm and 75 gpm, respectively.

Existing well W100, located just north of the former site, would be pumped at 50 gpm to recover what is presently believed to be local groundwater contamination. The observed contamination of well W100 implies the possible existence of surficial contaminant sources other than the pond south of the former site. Contamination of W100 could be attributed to seepage from the adjacent pond. Water from this pond was occasionally pumped into storm sewers which discharge into Bass Lake. Thus Bass Lake and the pond adjacent to W100 may be additional contaminant sources. Further Platteville groundwater investigations should be conducted in these areas.

G. Middle Drift Aquifer

March 3-4 and July 22-24, 1981 water level data from Middle Drift observation wells indicate natural groundwater movement is generally eastward in the area of known contamination (Figure 8). Two west-east cross-sections including wells W13, W11, W134, W117 and W116 with corresponding water level data for June 6, 1981 and March-April, 1978 were constructed by the USGS (Hult, personal communication, July 24, 1981; Hult and Schoenberg, 1981). The maximum eastward gradient observed from these four data sources is about 12 feet per mile. An average Middle Drift transmissivity of 15,000 gpd/ft was derived from short term (i.e., less than one hour duration) pumping test data (in Hult and Schoenberg, 1981).

Similar to the remedial plan for the Platteville, three wells are proposed for the withdrawal of contaminated Middle Drift groundwater. The first well, RW6, would be pumped at an average rate of 125 gpm to intercept contaminated groundwater moving eastward toward the bedrock valley (Figure 8). A second well, RW7, located east of the presently known extent of contamination, would be pumped at an average rate of 75 gpm to capture contaminated groundwater north and east of the bedrock valley. The third well, existing well W2 (located next to Platteville well W100), would be pumped at 50 gpm to withdraw local contamination due to the adjacent pond. The observed contamination of well W2 further implicates the adjacent pond and Bass Lake as possible surficial contaminant sources, as mentioned in the Platteville discussion. Further Middle Drift groundwater investigations should be conducted in these areas.

An independent alternative being considered in the Middle Drift aquifer is the use of a pumpout well near well W13 to remove the most heavily contaminated groundwater. A low pumping rate of 10 gpm is presently proposed for this well since disposal of the effluent would necessitate transport from the site.

IV. GROUNDWATER QUALITY ASPECTS

Groundwater quality in terms of polynuclear aromatic hydrocarbon (PAH) concentrations is considered here from both short-term and long-term perspectives. Projections of gradient control well quality are made for an initial 20-year period of operation. Effects of sorption, leakage and contaminated soil excavation are discussed in relation to the long-term prospect of "cleaning up" the groundwater contamination.

A. Gradient Control Well Quality Projections

Estimation of gradient control well discharge quality requires definition of the distributions of both PAH concentrations and travel time to the well within its area of influence. Areal concentration distributions in each aquifer were defined by constructing Thiessen polygons (Linsley et al., 1975) around wells for which PAH analyses were available. Groundwater in the aquifer area delineated by each polygon was assigned the quality indicated by the most recent analysis of water from the corresponding well. Quality was characterized for each well by "total" PAH, highest carcinogenic PAH, and highest "other" PAH.

The distribution of travel times in a gradient control well area of influence is dependent on the presence of a background gradient or flow trend. When no background gradient exists, groundwater flow in an aquifer converges radially toward a pumping well. In this case the distribution of groundwater travel time to the well is given by

$$t = \pi r^2 bn/Q \qquad (5)$$

where t = time of travel;

r = radial distance from well;

b = aquifer thickness;

n = aquifer effective porosity; and

Q = well discharge rate.

As determined by Sun (Reeder et al., 1976), the groundwater travel time distribution in the area of influence of a well pumping in a uniform flow field is defined by

$$t = (nb/Ti)\left\{ x + x_o \ln[\cos(y/x_o) - (x/y)\sin(y/x_o)]\right\} \tag{6}$$

where i is the background aquifer gradient, T is the aquifer transmissivity, x_o is defined by equation (4), and x and y are cartesian coordinates as depicted in Figure 3.

Equation (5) was used to construct concentric contour lines of equal travel time (isochrones) to proposed gradient control wells in the Mt. Simon-Hinckley aquifer. Equation (6) was used to produce isochronal maps for the area of influence of proposed gradient control wells in the Prairie du Chien-Jordan, St. Peter, Platteville and Middle Drift aquifers. Gradient control well travel time and aquifer quality maps were combined to obtain a first estimate of gradient control well discharge quality through time. Initial 20-year averages were then computed from these results.

Table 2, Gradient Control Well Discharge Quality Projected 20-Year Averages, shows the projections. The aggregate flow-weighted averages are on the order of 100 ng/l, 3,000 ng/l and 4,000 ng/l, respectively, for highest carcinogenic, "other" and "total" PAH,

TABLE 2

Gradient Control Well Discharge Quality
Projected 20-Year Averages

Aquifer	Plan	Well	PAH Concentrations (ng/l) Highest Carc.	Highest "Other"	"Total" PAH
Mt. Simon-Hinckley	1	SLP 11†	3.	50.	80.
	2	R-W23*	?	?	?
		R-W38*	300	4,000	7,000
	3	RW2*	?	?	?
Prairie du Chien-Jordan	1	SLP 10,15	200	9,000	10,000
		W70	30.	2,000	4,000
		SLP 4	5.	200	300
		W112	30.	3,000	5,000
	2	SLP 10,15	200	9,000	10,000
		W70	30.	2,000	4,000
		SLP 4	5.	200	300
		RW1*	20.	800	1,000
St. Peter	1	RW3*	30.	200	500
Platteville	1	RW4*	9.	2,000	2,000
		RW5*	70.	3,000	5,000
		W100**	30.	2,000	3,000
Middle Drift	1	RW6*	200	1,000	2,000
		RW7*	100	400	1,000
		W2**	200	50.	400
		Pumpout (W13)**	$0.3x10^9$	$0.6x10^9$	$2.5x10^9$

† SLP denotes St. Louis Park municipal well.
* Proposed new well.
** Estimated initial quality.

with the drift pumpout well in the area of worst contamination excluded. The list of PAH compounds monitored in area wells has not been consistent nor necessarily exhaustive. Estimates of "total" PAH are thus quite tentative. In projecting gradient control well quality, the highest carcinogenic PAH concentrations for different monitored wells were treated as though representing the same compound even though, for example, the compound is chrysene in one well and benzo(a)pyrene in another. "Other" PAH were treated in the same way. This procedure introduces a conservatism into the analysis which is warranted in light of the data uncertainties.

The PAH concentrations initially expected in a drift pumpout well are more than a million times higher than in the other gradient control wells. In the area of worst contamination (well W13), some measured PAH concentrations exceed reported solubilities by several orders of magnitude. This suggests the possible existence of a distinct fluid zone with a predominantly hydrocarbon character. A pumpout well in this case could reasonably operate at low pumping capacity and continue until the discharge concentrations decreased to levels below the reported solubilities.

The gradient control well quality projections account for sorption in the Middle Drift aquifer, but otherwise do not incorporate the effects of dispersion, sorption or leakage between aquifers. Dispersion or spreading of contaminants will occur as groundwater flows toward a pumping well. This spreading occurs primarily in the direction of flow. Peak groundwater concentrations presently observed in an aquifer would thus be reduced along the flow path to a well. The net effect of dispersion would be a smoothing of the gradient control well concentration history. The effects of sorption and leakage on gradient control well discharge quality are discussed in the following sections.

B. Sorption Effects

Sorption is the process by which PAH compounds adhere to the aquifer matrix. This process causes a partitioning of the compound between the groundwater solution and sorbed matrix phases. The distribution of a solute between these phases may be represented by a partition coefficient, K_p, defined as

$$K_p = C_s/C_w \tag{7}$$

where C_s is the mass of the solute species sorbed on the solids per unit bulk dry mass of the aquifer matrix, and C_w is the concentration of the species in groundwater solution (Means et al., 1979; Means et al., 1980).

The significance of the sorption process is that it retards the velocity of PAH movement through an aquifer relative to the velocity of groundwater flow. The ratio between these velocities is termed the "retardation factor" and is defined as

$$R = v/v_c = 1 + \frac{B}{n} K_p \tag{8}$$

where v is the velocity of groundwater flow, v_c is the velocity of PAH movement, B is the aquifer dry bulk density and n is the aquifer effective porosity (Freeze and Cherry, 1979). The method used to project bedrock gradient control well discharge quality assumes the contaminants move at the same rate as groundwater flow, i.e., no sorption. If sorption does occur in bedrock aquifers, the time scale of these projections would increase by a factor of R, as defined above.

The literature on PAH sorption concerns sorption on soil, sediment and artificial media. Values of the partition coefficient, K_p, are reported for eight PAH compounds on various natural and artificial media and range over several orders of magnitude (May, 1980; Means et al., 1979; Means et al., 1970; and Southworth, 1979). The generally lower values reported by May (1980) appear to be descriptive of the Middle Drift aquifer, because it is a sand and gravel aquifer expected to be low in organic carbon content - a physical characteristic of soils which has been positively correlated with K_p values (Means et al., 1979; and Means et al., 1980). Values of the octanol-water partition coefficient (a parameter related to K_p) reported for many PAH compounds by Yalkowsky and Valvani (1979) were used to extend the limited data of May (1980) by logrithmic regression. Resulting K_p values are 60 to 168 liters/kg for the five carcinogenic PAH, and 5 to 23 liters/kg for the five "other" PAH, most frequently showing highest concentrations in the monitored wells in St. Louis Park.

From this it is concluded that K_p values of 100 liters/kg for carcinogenic PAH and 10 liters/kg for "other" PAH are representative of the Middle Drift aquifer. These imply retardation factors, R, of approximately 600 and 60, respectively, for carcinogenic and "other" PAH. (Here equation 8 is used with B = 1.8 kg/liter and n = 0.3 as approximations for the drift.) Therefore, PAH are expected to move very slowly relative to the groundwater flow in the Middle Drift aquifer.

No information directly concerning PAH sorption in bedrock has been found in the literature. However, monitoring of the Prairie du Chien-Jordan aquifer has shown rapidly changing PAH concentrations which apparently result from pumping stress changes, and such observations are consistent with very low sorption. In addition, the widespread extent of contamination in the Prairie du Chien-Jordan appears to be the consequence of PAH transport at rates comparable to those for groundwater flow in the aquifer. The evidence thus suggests that PAH sorption is negligible in the Prairie du Chien-Jordan aquifer.

In light of the above, it is assumed that sorption effects can without serious error be disregarded in all the bedrock aquifers. This assumption may not be valid, however, for the bedrock confining beds.

C. Leakage Effects

Existing water levels in the aquifer sequence indicate in all cases a potential for downward leakage through the separating confining beds, or aquitards. The groundwater quality in an aquifer will be effected by the rate and quality of inflow received from the overlying aquifer and the time required for this inflow to cross the separating aquitard. The rate of leakage and time of travel through an aquitard are dependent on the difference in hydraulic potential between the overlying and underlying aquifers and the hydrologic characteristics of the aquitard.

The proposed gradient control well system itself would alter leakage rates in the contaminated area. Due to different pumping rates and hydrologic characteristics in the aquifers, the proposed system in most cases would increase the downward leakage. due to changes in pressure head As approximations over the area of contamination, the pumping would increase average leakage rates to the Platteville (from the Middle Drift) several-fold, to the St. Peter (from the Platteville and Middle Drift) by 50 percent, and to the Prairie du Chien-Jordan (from the St. Peter) by 25 percent. Leakage to the deeper aquifers would actually decrease somewhat because of the high pumping rates proposed in the Prairie du Chien-Jordan.

Estimated leakage travel times through the aquitards are on the order of 1 to 40 years through the basal drift, 70 years through the Glenwood shale, 50 years through the basal St. Peter and 700 years through the St. Lawrence-Franconia and Eau Claire formations. These estimates assume gradient control system operation as previously proposed and represent fluid travel times. Longer travel times apply for current conditions (except through the St. Lawrence-Franconia-Eau Claire). Sorption in the aquitards could substantially slow the movement of PAH relative to the groundwater.

Volumetric leakage rates in the area of contamination are sufficient to imply potential groundwater quality impacts in the bedrock aquifers. PAH have not yet leaked substantially through the basal drift, as evidenced south of the Republic site by very high concentrations in the Middle Drift (PAH >1,000,000,000 ng/l) and fairly low concentrations in the Platteville (PAH <100 ng/l).

But PAH leakage into the Platteville will eventually occur, and because of the very slow PAH movement in the Middle Drift due to sorption, it will occur over a long period. *remove till drift contaminated soils ?*

Leakage from the Middle Drift contaminated area could comprise 10 percent or more of the pumpage from Platteville recovery wells. This means that at best, a 10-fold dilution would be available in the Platteville for leakage from the Middle Drift. Therefore, significant groundwater quality impacts in the Platteville are expected to result from leakage.

Leakage enters the St. Peter from both the Platteville, through the Glenwood shale, and the Middle Drift, through till in the buried valley near the Republic site. A small portion of St. Peter recovery well pumpage (on the order of 1 percent) would be leakage from the contaminated area of the Platteville. The Platteville leakage would thus be diluted approximately 100-fold. Impact on groundwater quality in the St. Peter could be significant, especially under future conditions of PAH leakage into the Platteville from th[illegible].

There are no monitoring data to indicate whether or not Middle Drift groundwater contamination extends into the area of the buried valley. If it does, large groundwater quality impacts could result in the St. Peter, because Middle Drift leakage there could comprise 10 percent or more of the St. Peter recovery well pumpage. *will this be addressed in soil sampling effort?*

Leakage from the Middle Drift will affect successively deeper bedrock aquifers in the long term. The groundwater quality impacts will be lessened at greater depths due to dilution in each successive aquifer.

Groundwater quality in the Prairie du Chien-Jordan aquifer could be significantly affected by leakage depending on the groundwater quality of the St. Peter. Leakage from the St. Peter in the area of contamination would represent an estimated 1 to 10 percent of the pumpage from Prairie du Chien-Jordan recovery wells.

The Ironton-Galesville and Mt. Simon-Hinckley aquifers could be subject to future "slug loads" of PAH contamination by leakage. However, travel times of hundreds of years through the intervening aquitards are involved.

Multi-aquifer wells in St. Louis Park have been important conduits for downward movement of contaminants (Hult and Schoenberg, 1981). The Minnesota Department of Health has located and properly abandoned several multi-aquifer wells to date and is currently pursuing a program aimed at thoroughly completing this task. Any remaining multi-aquifer wells could result in downward movement of contaminants in addition to leakage through aquitards as discussed in this section.

D. Soil Excavation Effects

The possible excavation of contaminated soils in the Republic site vicinity has been discussed in a separate memorandum, number 618-7, entitled, "Contaminated Soils Management." That document identifies peat deposits at the south of the site as probable continuing "sources" of groundwater contamination in the drift.

Excavation of contaminated soils would be expected to yield little benefit to groundwater quality, unless coupled with removal and disposal of fluid from the "source" area and the underlying Middle Drift. Soil excavation alone would leave fluid in-place with PAH concentrations exceeding 1,000,000,000 ng/l [1 gm/l]. Although a substantial mass of PAH could be excavated with the soil, the remaining fluid presents a serious groundwater quality problem. Available information on PAH sorption implies that high PAH levels will persist in the Middle Drift groundwater for very long periods, perhaps thousands of years. Therefore excavation as considered above would not be a significant benefit to the groundwater quality.

Excavation coupled with fluid removal from the "source" area and the underlying Middle Drift could significantly reduce the impacts of leakage on groundwater quality in the bedrock aquifers. This would be a benefit if it could lower the peak groundwater concentrations of PAH in the Middle Drift by several orders of magnitude. High PAH concentrations would still persist in the Middle Drift, and gradient control wells there would need to continue pumping for an indefinite period. However, by reducing the peak concentrations substantially, the major long-term effects of PAH leakage from the Middle Drift could be restricted to the shallower bedrock aquifers.

Fluid removal would require one or more pumpout wells in the area of worst contamination in the Middle Drift as well as special handling of fluid encountered in excavating the shallower peat deposits. Disposal of the fluid would probably entail truck or rail transport because the extremely high PAH concentrations preclude treatment and disposal locally. Memorandum number G18-5 ("Alternatives for Ultimate Disposition of Gradient Control Well Discharges") discusses pumpout well effluent disposal.

It is important to note that available field data do not adequately define the "source" peat deposits and the zone of worst PAH contamination in the Middle Drift. In fact, there are no PAH data for the peat deposits, and the inference that they behave as PAH "sources" is based on indirect evidence. The zone of worst contamination in the Middle Drift is at present defined by two monitoring wells (W6 and W13, Figure 8) showing PAH concentrations exceeding solubility in water. Systematic field investigation must be conducted south of the Republic site to define the extent and nature of extreme PAH contamination prior to undertaking remedial measures there.

MRI data?

E. Long-Term Perspective

The long-term prospect of "cleaning up" the groundwater contamination depends primarily on hydraulic flushing times and the effects of sorption and leakage. The proposed gradient control wells would hydraulically flush the contaminated aquifer areas in an estimated one to three decades in most cases. Longer flushing times are estimated for the St. Peter (approximately one century) and the Mt. Simon-Hinckley under pumping plan 1 (one to two centuries).

It appears that PAH contamination in the Middle Drift aquifer will require many times longer than the flushing time to clean up, due to sorption. Carcinogenic PAH are estimated to move 600 times more slowly than the groundwater in the Middle Drift. This implies a "clean up" time of many thousands of years. It is therefore concluded that gradient control wells in the Middle Drift must operate indefinitely.

The long-term prospect for the Platteville and St. Peter aquifers reflects that of the Middle Drift, because of the impacts of leakage. Contaminated soil excavation coupled with fluid removal in the "source" area and the underlying Middle Drift could benefit these bedrock aquifers. These remedial measures could significantly reduce the degree of leakage impact, but the "clean up" times would probably remain very long. These bedrock aquifers would also appear to require indefinite operation of gradient control wells.

The Prairie du Chien-Jordan aquifer could be initially "cleaned up" in a few decades, but at least minor leakage effects would probably continue after that time. Leakage from the St. Peter reflecting that aquifer's current levels of contamination could imply significant impacts in the Prairie du Chien-Jordan for a century or more. These impacts appear to be of sufficient magnitude to preclude potable use without treatment of groundwater from some areas of the Prairie du Chien-Jordan.

The deeper Mt. Simon-Hinckley and Ironton-Galesville aquifers could also be "cleaned up" initially in a relatively short time. These aquifers will probably experience significant "slug loads" of contaminated leakage after a few centuries.

V. MONITORING AND SUPPLEMENTAL CONTROL

The monitoring plan proposed here is designed to insure effective control and removal of groundwater contamination by the gradient control well system. Additional monitoring of municipal and gradient control well discharge will be required to determine its suitability for municipal use or disposal to sanitary or storm sewer. The monitoring frequency and quality criteria for municipal use would be determined by the Minnesota Department of Health. Monitoring of discharge to sanitary or storm sewers would be in compliance with Metropolitan Waste Control Commission and National Pollutant Discharge Elimination System requirements.

Monitoring of the Mt. Simon-Hinckley and Ironton-Galesville aquifers would consist of municipal and recovery well discharge quality monitoring. Semi-annual water level measurements of existing Mt. Simon-Hinckley wells in the area should also be collected to insure flow is convergent to the recovery well(s) in this aquifer.

The proposed groundwater monitoring plan for the Middle Drift, Platteville, St. Peter and Prairie du Chien-Jordan aquifers would require installation of new monitoring wells. The locations of proposed new monitoring wells and existing wells in each aquifer are shown in Figures 4 through 8. All of these wells would be periodically monitored for water level and PAH concentrations during operation of the gradient control well system. It is suggested that measurement of the following PAH be included in the analysis of groundwater samples:

Carcinogenic PAH	Other PAH
Chrysene	Phenanthrene
Benzo(a)pyrene	Pyrene
Benzo(a)anthracene	Fluoranthene
Benzo(b)fluoranthene	Fluorene
Benzo(j)fluoranthene	Acenapthene

These constituents have displayed highest concentrations in past groundwater PAH analyses and are therefore considered general indicators of water quality.

The suggested frequency of data collection from the monitoring system is as follows:

- Annual PAH analysis of samples from all wells.
- Semi-annual PAH analysis of samples from wells located on or near the perimeter of observed contamination in each aquifer and the proposed new monitoring wells near gradient control wells.
- Semi-annual measurement of water levels in all wells.

Monitoring should be conducted by aquifer, with all water level measurements and samples from wells in the same aquifer obtained during the course of a few days. The monitoring data would be used to construct maps defining groundwater flow and quality in each aquifer on a semi-annual basis. The resulting descriptions of contaminant movement in each aquifer would provide an indication of the gradient control well system effectiveness.

Monitoring and control of groundwater use in the St. Louis Park area is also essential to effective gradient control well system performance. This pertains particularly to the Prairie du Chien-Jordan and St. Peter aquifers. The gradient control well system was designed for flow conditions existing under present use of these aquifers. The addition or removal of pumping stresses in these aquifers may change the flow pattern depending on the location and magnitude of the stress. The monitoring plan proposed above would allow observation of the aquifer response to these changes in groundwater use. In general, groundwater pumping inside areas of observed contamination is favorable, but would require quality monitoring. Control of groundwater use outside these areas may be necessary if it adversely affects the flow of contaminated groundwater.

The gradient control well system must be flexible. Adjustment of pumping rates or installation of additional gradient control and monitoring wells may be necessary due to unforseen changes in flow patterns or the discovery of new zones of contamination. Successful implementation of the system would require the oversight of a designated operator or operating agency. MPCA? The operator's responsibilities would include compilation and interpretation of monitoring data, documentation and control of water use, and prescription of necessary gradient control well system modifications.

VI. SECONDARY IMPACTS

Contaminated groundwater flowing toward gradient control or recovery wells may enter previously uncontaminated aquifer areas. This would preclude unmonitored use of groundwater at any location between gradient control wells and zones of observed contamination in an aquifer. Present or future nonmunicipal groundwater use in these areas would require quality monitoring and appropriate means of disposal. Other impacts on nonmunicipal users in the St. Louis Park area may include restriction of water use if it is can State do this legally? detrimental to the gradient control well system effectiveness, and increased pumping costs due to lowering of water levels from gradient control well pumping.

Implementation of the gradient control well system would require acquisition of land for the emplacement of new monitoring and pumping wells. Additional land may be required for possible treatment facilities and pipelines routing gradient control well discharge to sewer systems.

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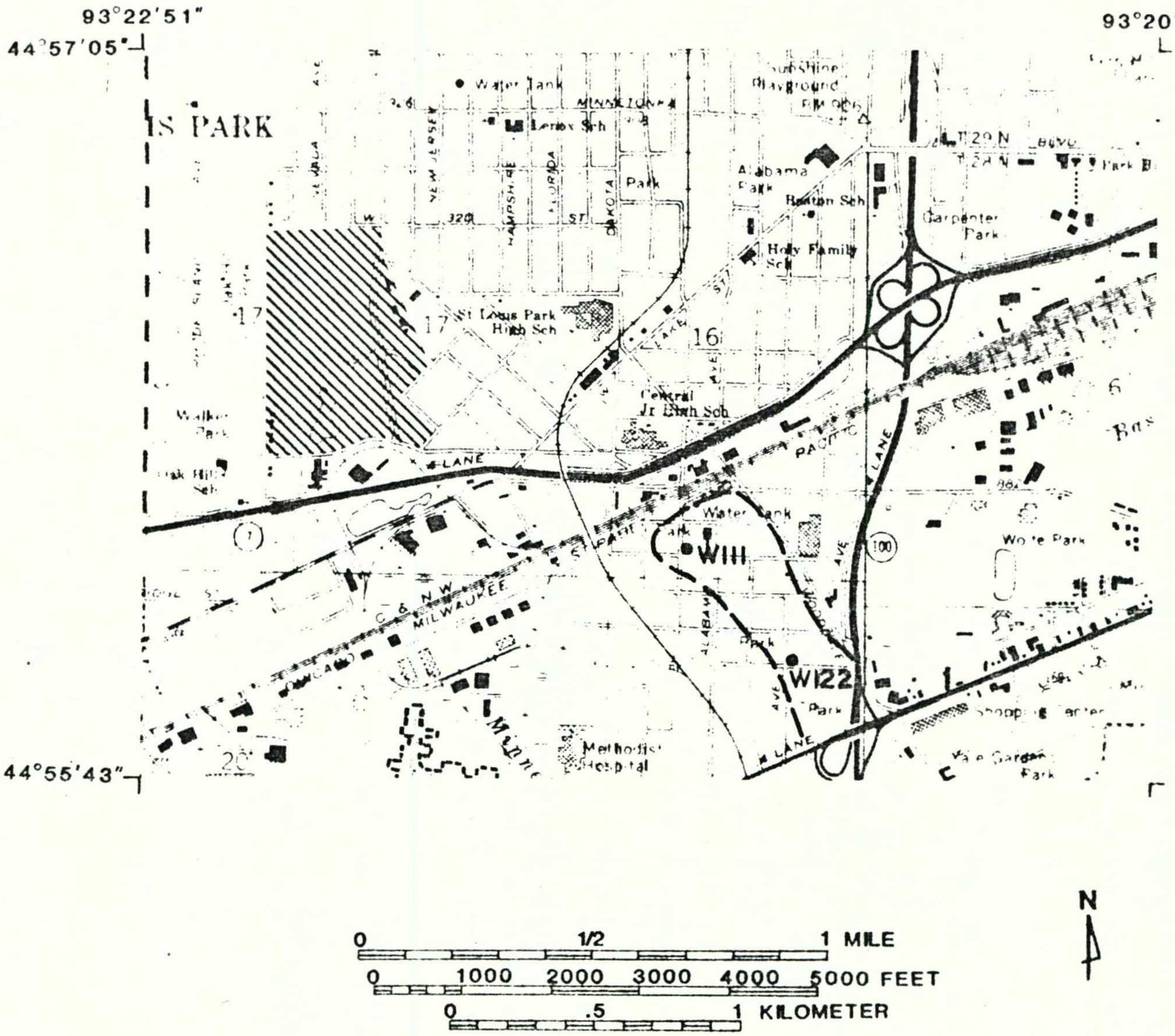
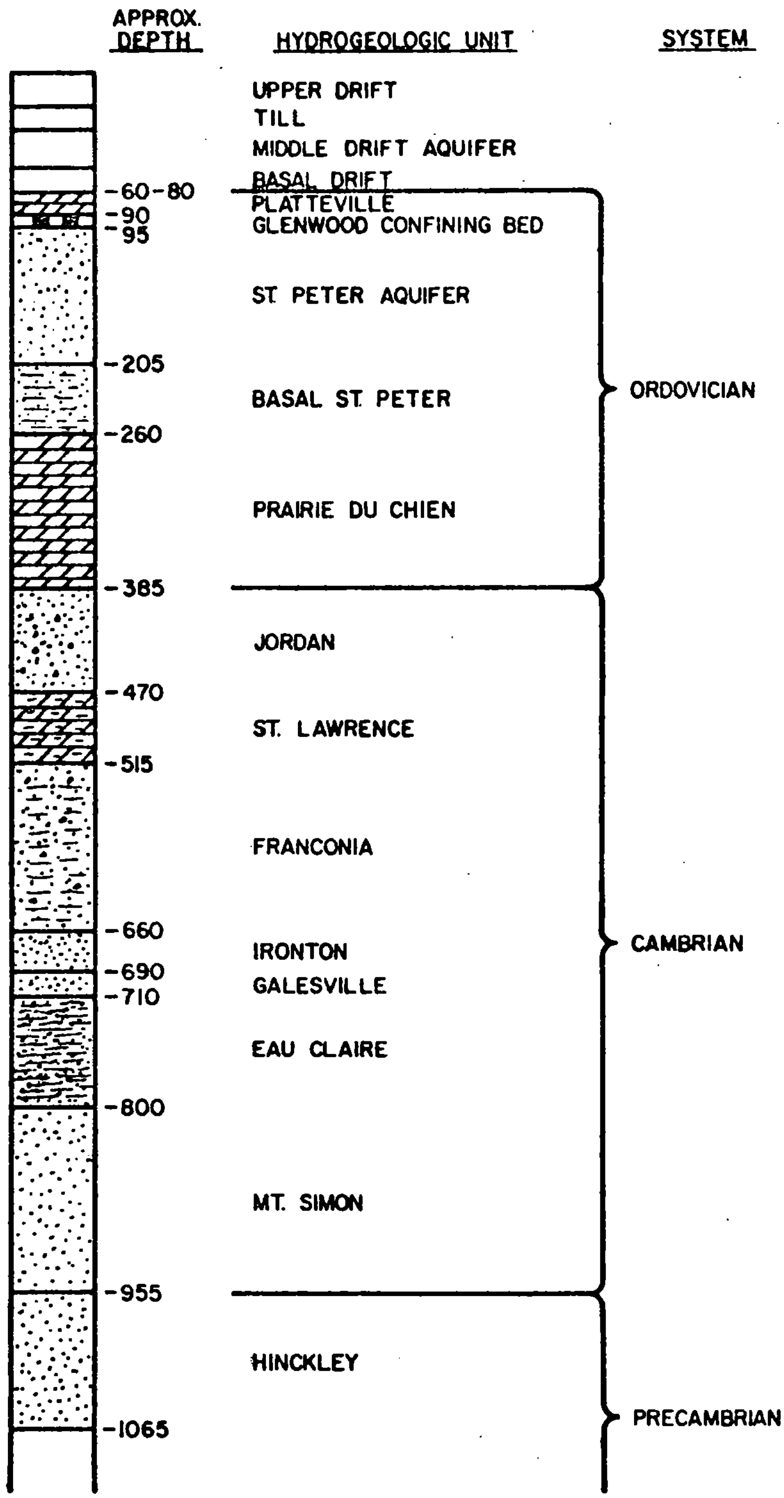


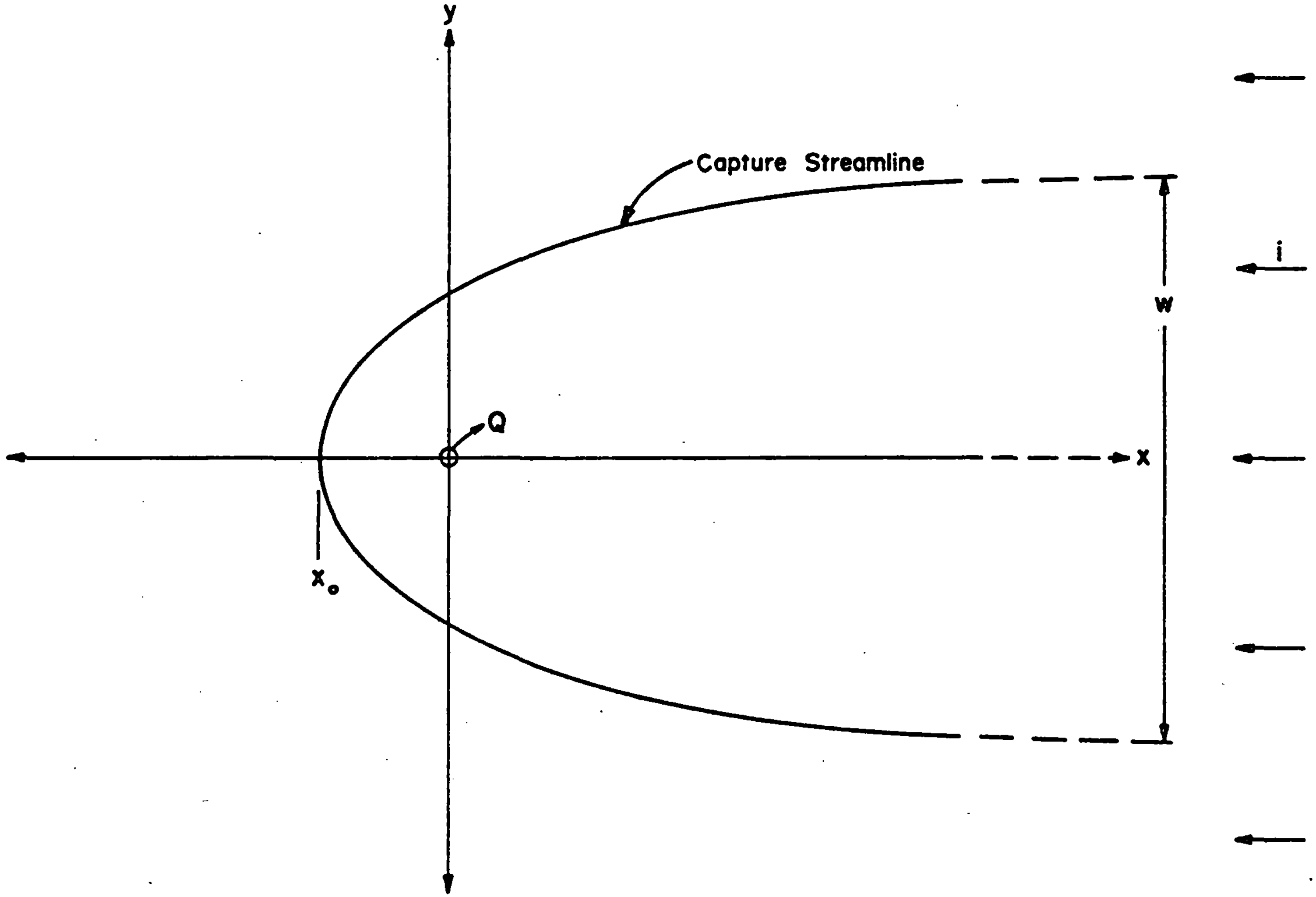
FORMER REPUBLIC CREOSOTE SITE

ASSUMED BEDROCK VALLEY BOUNDARY

	E.A. HICKOK & ASSOCIATES	9-22-81
LOCATION OF FORMER SITE AND BURIED BEDROCK VALLEY	HYDROLOGISTS-ENGINEERS MINNEAPOLIS-MINNESOTA	1



GENERALIZED STRATIGRAPHIC SEQUENCE IN ST. LOUIS PARK AREA	E.A. HICKOK & ASSOCIATES HYDROLOGISTS-ENGINEERS MINNEAPOLIS-MINNESOTA	9-22-81 2



	E.A. HICKOK & ASSOCIATES HYDROLOGISTS-ENGINEERS MINNEAPOLIS-MINNESOTA	9-22-81
WELL PUMPING IN UNIFORM FLOW FIELD		3

NON-RESPONSIVE

[redacted]

FIGURE 4: MT. SIMON – HINCKLEY AQUIFER

NON-RESPONSIVE

[redacted]

NON-RESPONSIVE

[redacted]

NON-RESPONSIVE

[redacted]

FIGURE 7: PLATTEVILLE AQUIFER

NON-RESPONSIVE

[redacted]

FIGURE 8: MIDDLE DRIFT AQUIFER

NON-RESPONSIVE [redacted]

MEMORANDUM NO. G18-10

DATE: SEPTEMBER 4, 1981

TITLE: ST. LOUIS PARK GROUNDWATER CONTAMINATION STUDY-WELL OPERATING COSTS

ABSTRACT:

THIS MEMORANDUM ANALYZES THE WELL OPERATING COSTS FOR THE GRADIENT CONTROL WELLS OUTLINED IN TASK 2030 (MEMORANDUM NO. G18-4.) THE OPERATION COSTS ARE BASED ON THE DISCHARGE QUANTITIES OUTLINED IN TASK 2060 (MEMORANDUM NO. G5-6). THIS MEMORANDUM REPRESENTS COMPLETION OF TASK 2070 OF THE REFERENCED PROJECT.

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WELL OPERATING COSTS AND ESCAPED WATER INTERCEPTION

This memorandum analyzes the well operating costs for the gradient control wells outlined in Task 2030 and the discharge quantities outlined in Task 2060.

The well operating costs are for the gradient control wells necessary for interception of the contaminated groundwater. Aquifers considered in this cost analysis are the Middle Drift, Plattville, St. Peter, Prairie du Chien-Jordan and Mt. Simon-Hinckley. The location of the proposed gradient control wells are shown in Figure 1 and the corresponding average discharge rates summarized in Table 1.

In determining the well operating costs, several assumptions have been made as follows:

Normal Pumping Levels (feet)

Mt. Simon-Hinckley	- 375 feet
Prairie du Chien-Jordan	- 175 feet
St. Peter	- 110 feet
Plattville	- 35 feet
Middle Drift	- 40 feet

Well Discharge Head - 150 feet

Power costs - $0.06 per Kw/hr.

Overall Pump-Motor Efficiency - 70%

Labor - $15.00 per hour

Based on these assumptions the total operating costs for operation of the gradient control wells was determined and is presented in Table 2. The costs are per year and do not include any major maintenance expenses. Labor costs are based on one-half hour per well per day at a cost of $15.00 per hour. Normal maintenance costs are based on an annual expenditure of 5% of the cost of the well pump and motor, which is estimated at $200 per horsepower.

NON-RESPONSIVE

[redacted]

TABLE 1

GRADIENT CONTROL WELL DISCHARGE QUANTITIES

Aquifer	Plan	Well	Discharge (gpm)
Mt. Simon-Hinckley	1	SLP 11†	600
	2	R-W23*	300
		R-W38*	300
	3	RW2*	600
Prairie du Chien-Jordan	1	SLP 10,15(combined)	800
		Park Theater (W70)	1000
		SLP 4	800
		Old SLP 1 (W112)	1500
	2	SLP 10,15 (combined)	800
		Park Theater (W70)	1000
		SLP 4	800
		RW1*	800
St. Peter	1	RW3*	300
Platteville	1	RW4*	150
		RW5*	75
		W100	50
Middle Drift	1	RW6*	125
		RW7*	75
		W2	50

† SLP denotes St. Louis Park municipal well

* Proposed new well

TABLE 2

OPERATING COSTS
GRADIENT CONTROL WELLS

Aquifer	Plan[2]	Power Costs Pumping	Power Costs Energy[1]	Normal Maintenance	Labor	Total
Mt. Simon-Hinckley	1	$23,650	-0-	$600	$ 2,737	$26,987
	2	23,650	$500	600	5,474	30,224
	3	23,650	500	600	2,737	27,487
Prairie du Chien-Jordan	1	188,700	1,000	4,810	13,700	208,210
	2	156,475	1,000	3,990	13,700	175,165
St. Peter	1	11,765	500	300	2,737	15,302
Platteville	1	7,196	1,500	200	8,211	17,107
Middle Drift	1	6,896	1,500	200	8,211	16,807

1 Heating and cooling costs for pump house(s). Existing SLP wells not included

2 Refer to Table 1 for wells.